Working memory and learning in children: a matter of attention

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Abstract

Memorizing is crucial for human beings because it constitutes the fundamental step in acquiring knowledge. Among the different memory systems, the one called « working memory » works continuously to simultaneously memorize and process information. It is particularly important in children who are continually confronted to learning situations. It has long been considered that memorizing required verbalizing and repeating. The present paper offers an alternative conception: working memory relies on attentional mechanisms constrained by time and do not depend on verbal characteristics. The empirical analyses we present here do not only conduct to important theoretical conclusions, they also give a glimpse of practical applications for preventing school failure.

Key-words

Working memory, attention, cognitive development, school learning

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Preamble

Memory is a crucial cognitive function for human beings. It constitutes a fundamental step in acquiring new knowledge. Without memory, there is no storage of information, and without storage of information, no learning is possible.

Human memory exploration started more than a century ago with James (1980) introspective studies. From that time on, cognitive psychology researchers never stopped studying it and trying to identify its characteristics and understand its functioning. Nowadays, several kinds of memory are distinguished: Among those, working memory (WM) constitutes the essential interplay between perception, long-term memory and action. Indeed, WM is a mental structure that has a double function. On the one hand, as its name indicates, it is devoted to a memory function permitting a temporary maintenance of information. On the other hand, it is also responsible for the processing of information coming from the environment and for the manipulation of already acquired knowledge. In this sense, it is involved in most of the cognitive activities we have to deal with each day. Indeed, these activities (e.g., to convert the price of a product from euro to franc, read a novel, or even follow a conversation) consist in numerous stages of information processing but also in the temporary maintenance of the intermediary outcomes of these processing phases. For example, in order for you to understand what your interlocutor is saying, you have not only to process his/her continuous stream of words, but you also have to keep the start of the sentence in memory, otherwise you cannot understand the message. Working memory is thus actually a memory that is working.

From the seminal work of Baddeley and Hitch (1974), WM is considered as the cornerstone of the cognitive system. For that matter, many studies demonstrated that WM capacities are closely linked to general capacities of reasoning, reading comprehension and problem solving (e.g., Kyllonen & Christal, 1990).

If WM is required for adult to perform daily cognitive activities, it is, all the more, essential for child who is continuously learning. How do children manage to process and memorize information simultaneously? And, as a consequence, how do they acquire new knowledge and skills? What are the cognitive parameters constraining WM performance? And, as a consequence, what factors affect learning? The first answers we propose in the present paper come from a research project that has a fundamental aim; all the while having direct applications on learning methods and more particularly school learning.

State of the art

Even in its more elementary stages as the short-term maintenance of a few stimuli (e.g., remembering a phone number a short while after having encoded it), memorizing has long been associated with language capacities (i.e., « to memorize, you have to rehearse », see Baddeley, 2007 for a review). Learning being undeniably mediated by a memory stage, this memorization would be difficult or even ineffective in children with restricted language capacities or with specific pathologies (e.g., dysarthria).

However, an alternative conception came up with works initiated by Barrouillet and Camos in the early 2000's. It is based on a new theoretical model of WM : the TBRS model for Time-Based Resource Sharing model (Barrouillet, Bernardin & Camos, 2004). As we will see, this model places attention at the heart of the memory system and hence, at the heart of the cognitive functioning permitting learning.

The Time-Based Resource Sharing model (TBRS)

The TBRS model is a functional model of WM. In this sense, it describes the temporal sequence of cognitive processes involved in the execution of a WM task. Thanks to the development of a new experimental paradigm, this model supports an original conception of the relations existing between processing and storage activities. Our experimental paradigm is a double task situation in which participants have to memorize series of stimuli while concurrently performing processing on other stimuli interleaved between two memory stimuli. This paradigm permits the manipulation of a wide variety of parameters (the nature of the to-be-maintained and to-be-processed stimuli, the kind of processing, the length of the to-be-maintained series, the number of to-be-processed stimuli). Most importantly, it also has the great advantage of controlling carefully the temporal sequences of the mental activities realized by the participants. Contrary to the classical tasks in which participants are free to perform activities at their own rhythm and to interrupt these activities as they want, in our paradigm, stimuli appear in a computer screen according to a preset and controlled rhythm. Thus participants are constrained to conform to a relatively high rhythm (which we can manipulate). As such, it is difficult for them to engage in any strategy that we might not be able to control. As we will see in the following section, it is essential to perfectly control the temporal course of the cognitive processes involved in performing the tasks.

The TBRS model is based on four assumptions. First, processing as well as memory maintenance require attention, which is a limited resource that hence has to be shared between both components of the task. Second, as soon as attention is switch away from memory traces, their activation suffers from a time-based decay. In other words, as soon as participant's attention is diverted from the to-be-maintained elements, their traces disappear little by little from memory, more or less as a picture becoming more and more blurred. This makes their retrieval difficult, or even impossible at a given time. Hence, before their complete disappearance, decaying memory traces have to be reactivated by means of attentional focalisation. Third, the focus of attention can be devoted to one activity at a time only. In other words, when attention is dedicated to an activity such as reading a digit at a given time, it is impossible to perform any other controlled activity at the same time (e.g., reactivating to-be-maintained memory traces). Therefore, WM functioning is necessarily sequential. Henceforth, any processing activity that captures attention impedes concurrent maintenance of information because it prevents the reactivation of memory traces. Then, to perform a WM task, attention has to be shared between processing and maintenance of information through a rapid and frequent switching.

Given this theory, how do we manage to memorise information and acquire new knowledge? By verbalising or repeating them again and again? No, not only! According to our conception, the mechanism responsible for the maintenance of information is an attentional mechanism: attention must be shared in a time-based manner between activities involved in the task at hand.

Accordingly, recent studies conducted in adults (e.g., Barrouillet, Bernardin, Portrat, Vergauwe, & Camos, 2007;

Barrouillet, Portrat & Camos, 2011; Portrat, Barrouillet, & Camos, 2008) are consistent in indicating that memory performance is impaired by a concurrent cognitive activity and even more so under high proportions of attentional capture induced by this activity. What happens in children? Do children have such an attentional mechanism, and if so, do they use it?

WM functioning in 10 years-old children

The question of the nature of the mechanism responsible for the temporary maintenance of information is important, not only for WM functioning but also for the global efficiency of the cognitive system. As we highlighted above, memory capacities have long been considered as highly linked to language mechanisms. In this sense, many researchers considered that to memorize stimuli, we had to verbalize and rehearse them. However, the sole rehearsal (being vocal or subvocal) of a verbal material induces a coding of its shallow characteristics (phonological essentially).However, to have a chance of memorizing information at long term and hence to acquire new knowledge, information has to be deeply encoded (Cowan, 1999). For example, we are frequently unable to retrieve the name of the brand this American famous model is representing. Even if this advertising campaign is displayed all over the town, as long as we do not deliberately focus our attention to these posters, we will only retain superficial characteristics (e.g., the model's position or clothes). Neither the advertising investigator, nor the precise carried message is encoded. Attention plays a major role in the construction of our representation of information by permitting a richer as well as longer lasting coding (Craik & Lockhart, 1973). Attentional encoding and maintenance of information seem thus to be important factors for successful learning.

The aim of the studies we conducted in children was to demonstrate that the previously described attentional mechanisms are present and functional before adulthood (Portrat, Camos, & Barrouillet, 2009). With that in mind, we studied the effect of the duration of the attentional capture induced by the processing activity on memory performance of 10 years-old children. Children had to memorize series of letters while performing a location judgment task about the position of squares appearing successively on the computer screen. We manipulated the duration of these location judgement activities by varying either the discriminability between spatial location of the targets or the contrast between the targets and the background. These manipulations are known to increase the attentional demand induced by the target search stages during a visual scene analyse (e.g., Heitz & Engle, 2007). Hence, we expected that the condition inducing a longer attentional capture (low discriminability and low contrast) would give rise to the lowest recall performance.

As expected, it took children more time to judge the spatial position of the squares when those were hardily discriminable or poorly contrasted from the background. This increased attentional capture in cognitive processing led to reduced memory performance. Even if these data are in accordance with our expectations, they are far from being intuitive. How can it be that processing a visual scene impedes concurrent maintenance of verbal information? We will firstly present the theoretical consequences of our results regarding the maintenance mechanism in children as well as the corresponding consequences for cognitive development in general. Then and finally, we will propose some possible applications for school learning as well as for school failure.

Theoretical interpretations

The main results presented here come from the comparison between experimental conditions involving the exact same processing task (i.e., location judgment) on the same material (i.e., squares). Thus, one can easily assert that, even if these visual tasks do involve any verbalisation (e.g., "if the square is in the upper side of the screen, I press the right key"), it is the same in both cases. However, our results show that one of these two tasks (the one for which the cognitive cost is higher) induces lower concurrent memory performance. This clearly constitutes evidence that language is not the sole mediator of the memory capabilities. If it were the case, children would have been able to memorize the same amount of letters in both conditions. The only way to interpret our results is to consider that the maintenance of verbal information does not only depend on language mechanisms but also on a time-based sharing of attentional resources between the different cognitive activities required by the task.

However, if children do actually use a maintenance mechanism similar to adults, these two groups are not on an equal footing for all that. Indeed, all other things being equal, children seem to suffer from a memory loss that is three times as large as the one observed in young adults (Barrouillet et al., 2007; Exp. 2). Two factors can explain the fact that time is more deleterious for the memory traces of children. (1) the attentional refreshing mechanism is presumably less effective in children. Hence, while adult will be able to efficiently use the free pauses between any two successive processing episodes, children will only be able to perform some light reactivation of the traces. (2) It is also possible that children suffer from a restricted capacity to switch attention between processing and maintenance activities. It would be less easy for children to switch rapidly and frequently from a processing activity to a maintenance activity. Besides, it is known that attentional switching is not efficient before 7 years of age (Henry & Millar, 1993). Broadly speaking, our results suggest that developmental changes from childhood to adulthood affect the efficiency of the mechanisms involved both in processing and in storage, as well as in their coordination, rather than the structure or the functioning of WM per se.

Applications

As we have seen, our conception of the WM functioning and our results highlight the particular importance of the attentional mechanisms in short term memory and, as a consequence, in knowledge acquisition. In this sense, our theory offers a privileged explanatory framework for school difficulties associated with attentional disorders: Attention deficit hyperactivity disorder (ADHD). Broadly speaking, the symptoms that are shown by ADHD children include more particularly a lack of sustained attention and an inability to concentrate. Thus, with the identification of the attentional mechanisms of maintenance used by children in mind, it is possible to explain learning difficulties encountered by ADHD children in terms of a dysfunction of those attentional mechanisms. One can reasonably imagine that these children, relying on low attentional capacities only, simply do not use this advanced attentional focusing mechanism and just verbally rehearse the to-be-maintained information. However, as mentioned above, this low-level strategy allows only the coding and maintenance of the shallow characteristics of information. If a stimulus is only poorly represented since the very first basic but nonetheless essential stages of encoding, it is not surprising, then, that more comprehensive learning difficulties emerge. One can also assume that ADHD children, even if they actually use the same attentional mechanism as their peers, are penalized by a lack of efficiency of this mechanism or by an attentional lability that would impede adapted and adequate switching of attention between several cognitive activities.

Finally, our theory also yields practical recommendations likely to sustain school learning. In cognitive activities requiring maintenance as well as manipulation of information, the core difficulty is to manage with the limited resources in the most economic and efficient way given the temporal constrains. As highlighted above, WM is extremely solicited during learning (Gavens & Camos, 2006). It is thus essential to avoid its overload by information that has to be maintained and / or processed simultaneously. Depending on the objective of the teacher or the difficulties encountered by the pupil, either one of the two WM activity (maintenance or processing) could be simplified and lightened to facilitate the carrying out of the other. To minimize the amount of to-be-maintained information in order to leave a maximum of resources available for processing, one possibility is to supply a maximum of supports to pupils (often visual as collective posters, words notebook, etc…). Little by little, when information has been frequently encountered and when it is properly represented in long term memory, its retrieval and its active maintenance become less and less costly and the child can thus grow away from these temporary tools. The second possibility to relieve WM is to break the processing activity down into several sub-stages (step by step progress) while using written support to maintain intermediary outcomes of these processing stages. For example, at the beginning of the acquisition of the arithmetic operation of division, children are asked to write down the subtraction to determine the remainder. This technique, that simply consists in avoiding memory to be overloaded by an intermediary processing outcome, can be applied to many learning domains (e.g., text comprehension, arithmetic, and so on). In all cases, the most important point is to avoid the time-based constrain of activities as much as possible. As seen here, the more a cognitive activity has to be rapidly performed, the more it impedes any other activity to be carried out and the more its cognitive load is important.

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